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Deposition and Retention of Sprays. III.
Apparatus and Methods for Laboratory Spraying

DIGEST

This paper presents a laboratory method for the study of the deposition and retention of insecticide and fungicide sprays. In this method synthetic surfaces attached to a rotating turntable are sprayed with an atomizer type sprayer, to which is attached an overhead reservoir containing the spray suspension. The effects of time, pressure, concentration of toxicant, and type of sprayer were investigated in connection with the performance of the apparatus, and the method finally evolved was found to give accurate and reproducible results. The plates sprayed by this method may be readily subjected to artificial weathering tests, and retention coefficients calculated. Typical results are given.

Deposition and Retention of Sprays.III.

Apparatus and Methods for Laboratory Spraying.*

DONALD E. H. FREAR †

THE MOST IMPORTANT CONSIDERATIONS involved in the performance of any insecticide or fungicide, apart from the inherent toxicity of the material used, are the amounts of toxicant deposited and retained following application. A highly toxic material may fail to show insect or disease control under practical conditions because of low initial deposition or poor retention, or a combination of the two. Conversely, a substance of less toxicity may produce satisfactory control because of its superior qualities of deposition and retention.

Since this is true, it follows that an increase in these desirable qualities should be one goal toward which research workers, particularly those in the field of insecticide and fungicide chemistry, should strive. Materials long used may be improved, and substances discarded because of unsatisfactory performance may be rendered useful.

Unfortunately, the problem of how to improve the qualities of deposition and retention of insecticides and fungicides is neither simple nor easy. There are two obvious ways to study such a question; first, by a routine testing of a large number of possible materials in all manner of combinations, a tremendous undertaking; or second by the application of knowledge of the fundamental processes involved to a specific problem. The latter approach certainly is the more scientific one. However, in spite of a great deal of work on the subject, knowledge of the fundamental principles involved in spray deposition and retention is very limited. This is due in some measure, at least, to the fact that field experiments as usually conducted are lengthy and costly.

Field experiments, although they may be expected to yield results of a definitely practical nature, require nearly an entire growing season, as well as rather costly and laborious chemical analysis. Such studies have been reported by a number of workers, including the author (3 and 4). Laboratory studies on spray deposition and retention are quicker and more readily carried out, although they do not always correlate with the results secured in the field (6 and 14). Field studies, even though closely controlled, are subject to a number of unknown and uncontrollable variables, while laboratory studies may be carried out with a much higher degree of precision. For this reason laboratory studies are to be preferred in any attempts to investigate the more fundamental aspects of the problem.

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A number of ingenious devices and techniques have been proposed for laboratory spray studies. None of these, however, exactly met all of the requirements of the investigations which the author had in mind. Therefore, about eight years ago work was begun on apparatus for laboratory spraying which would more nearly meet the specific needs of spray deposit investigations. During the following years the apparatus has been used for deposition and retention studies on both insecticides and fungicides. As experience with the apparatus increased, changes in the design were made, so that the present apparatus now represents the accumulated experience of a number of workers[1] over a period of approximately eight years. It is the purpose of this paper to describe this apparatus, and to give some information as to its performance and possibilities. It is hoped that the presentation of this information will be of value to other investigators in the field.

GENERAL CONSIDERATIONS

Definitions.—Before entering into a discussion of the theoretical aspects of deposition and retention, it may be wise to define the terms used. In the past there has been considerable confusion of terms used in this type of investigation. The terminology used in this paper conforms in general to that suggested by the Committee on Standardization of Fungicidal Tests of the American Phytopathological Society *(8)*, except for the term *retention*. Retention has been used in the earlier papers in this series to denote the property of a spray deposit to resist removal by weathering and will be used throughout this present paper in reference to *tenacity*, the term preferred by the committee.

Theoretical considerations.—Probably the best way to discuss the processes involved in the deposition and retention of a spray is to use a concrete example. A suspension of the finely divided solid is prepared and placed in the spray tank. By the proper application of a mechanical force this suspension is forced through an orifice under pressure and at this point is broken up into droplets of various sizes. The amount of the flow and the size of the droplets will depend on the amount of force (pressure) applied to the liquid, the size and conformation of the nozzle and orifice, the physical properties of the liquid, surface tension, viscosity, etc., as well as the temperature and humidity of the air.

Depending on the particle size of a suspended material, such as lead arsenate, each droplet may contain one or more particles of the suspended solid. During their passage through the air these

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droplets may lose water through evaporation unless the humidity is 100 per cent. Some of the smaller droplets may evaporate completely, leaving the solid particles of suspended material free to float away. A certain percentage of the droplets reach the target toward which they were directed. Here the behavior of the drop is further influenced by the character of the surface against which it strikes. In a remarkable series of photographs, Upholt and Hoskins *(13)* have illustrated the changes in conformation of droplets at the moment of impact and immediately thereafter. As the drop of liquid strikes the solid surface there is usually a more or less pronounced rebound, resulting in spattering if the drop is of sufficient size. Following this there is a subsidence, during which time the drop assumes a characteristic shape, depending on the composition of the liquid and its physical properties and the character of the surface. The extent to which a drop spreads on the surface is the resultant of these forces, the surface energy of the solid, the surface tension of the liquid, and the wetting and spreading ability of the liquid. Eventually these come to equilibrium and form a drop pattern characteristic for the liquid and surface involved.

If the liquid wets the solid on which it was deposited, it tends to spread out in a thin film, with the angle of contact approaching zero. If the liquid does not wet the surface, discrete droplets, more or less spherical in shape, rest on the surface without wetting it. In this case the contact angle is 180 degrees. The surface tension of the liquid tends to pull drops into the shape having the smallest surface area, the sphere. Intermediate between no wetting and complete extension of the drop on the surface there are, obviously, many degrees of wetting and spreading.

The droplet of spray suspension, now at rest on the surface to which it has fallen, normally begins to evaporate at once. The speed with which the liquid phase is evaporated depends upon the humidity of the atmosphere, the temperature, the vapor pressure of the liquid, and the free surface exposed. As evaporation proceeds, the ratio between suspended solids to liquid becomes progressively greater. In cases where the liquid phase contains dissolved substances as well as suspended material, the opportunities for chemical reactions are greatly increased. Gases may have been dissolved in the spray droplets in their passage through the air, and these may function as chemical reactants at this time.

When evaporation becomes complete, the dry residue consists of the solids which were originally suspended or dissolved in the liquid phase. These particles are retained by the surface upon which they have been deposited with varying degrees of tenacity. Among the factors which determine the degree to which these particles adhere are the size of the particles, their shape, the nature

of the particle surface, and the nature of the surface (substratum) upon which they are deposited. When subjected to weathering, which includes mechanical abrasion, rainfall, dews, and atmospheric gases, solubility and chemical reactivity play an important part, along with the other factors mentioned in determining the amount of residue retained upon the surface. Moore *(10)* has indicated that in some cases electrical charges on the particles and on the substratum may have a significant effect in determining adherence.

### DESCRIPTION AND TESTS OF NEW APPARATUS

In the following pages is presented a description of the apparatus and method as used at present in this laboratory. As mentioned previously, this apparatus and technique represent the results of a number of trials over a period of years and is the expression of ideas suggested by a number of workers. An attempt will be made to characterize the performance of the apparatus and to demonstrate the accuracy and reproducibility of the laboratory method as a whole. It is hoped that this information will be of some use to other research workers and will stimulate further work on the subject of spray deposition and retention.

Apparatus.—Two views of the completed apparatus are given in figures 1 and 2. The principal parts are: (1) A rotating circular table,


Fig. 1.—Complete spraying apparatus, showing relation of rotating turntable to atomizer sprayer. The motor and driving gears are located underneath the turntable and are not visible.

Fig. 2.—Close-up of atomizer sprayer assembly, showing reservoir above atomizer, stirring motor, and connections. The large flexible metal hose leading down from the atomizer is used to catch the spray stream when cleaning the atomizer.
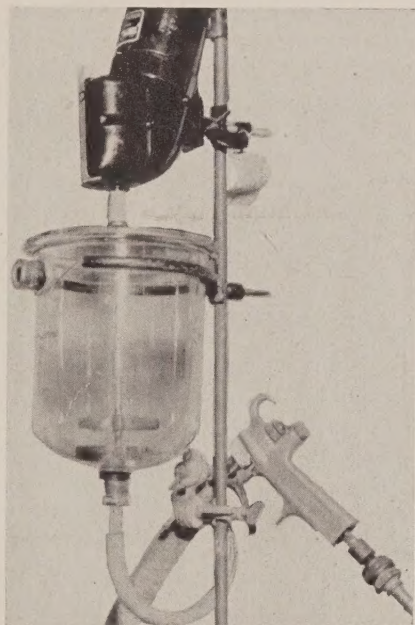
4 feet in diamter, mounted on a central vertical shaft, and rotated at a speed of 14 revolutions per minute by a synchronous motor (one sixteenth h. p.) connected by a belt through a speed reducer which is geared directly to the shaft. The reducing gear, motor, and bearings for the table axle are bolted firmly to an angle iron frame which forms a base to give the assembly complete rigidity. The turntable is made of one piece of ¾ inch plywood cut in a circle 4 feet in diameter. (2) A series of 24 wooden blocks arranged around the periphery of the wheel on its top surface. These blocks are beveled so as to form a complete circle, with their outer surfaces cut to
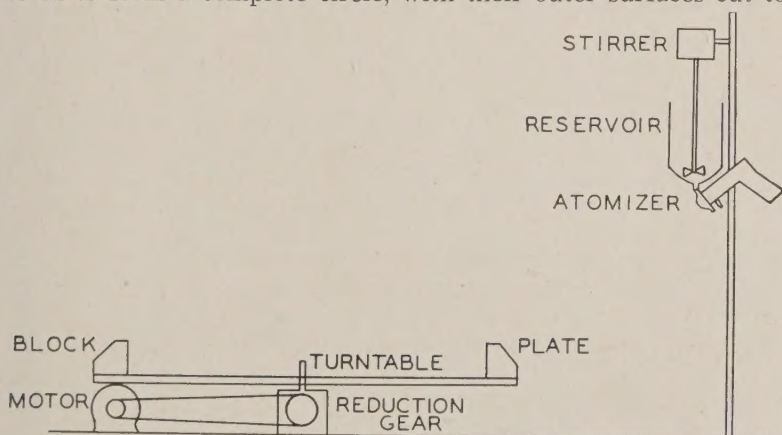
Fig. 3.—Diagram showing the arrangement of the essential parts of the laboratory spraying apparatus.

present surfaces approximately 5 inches square at an angle of 45 degrees to the table surface. Figure 3 shows a vertical section through the center of the turntable.

(3) A spray nozzle, mounted so that the spray stream is directed at right angles to the beveled surface of the block. The types of nozzles tested will be discussed in more detail later. The surface to be sprayed is attached to the beveled surface of the wheel, sprayed for the required length of time, dried, removed, and the deposit analyzed. For retention studies the dried deposit is subjected to artificial rainfall usually applied through the same nozzle used to apply the deposit. This also will be discussed in more detail later.

Types of experimental surfaces used.—A wide variety of surfaces, both natural and synthetic, have been used for laboratory studies. Many workers have used living plant surfaces, particularly leaves and fruits. In such tests, the plants or fruits to be tested are usually rotated in the stream of spray and the residue determined by mechanical, chemical or biological means. Swingle, Phillips, and Gahan *(12)*, for example, used living leaves and Newcomber *(11)* used apple fruits. Many other workers have used synthetic surfaces. McCallen and Wilcoxon *(7)* used glass microscope slides, Dawsey et al. *(2)* used wax-coated mica plates, Borden and Hensill *(1)* wax-coated bottles, and Horsfall et al. *(5)* and a number of English workers have used glass plates covered with cellulose nitrate.

Since there is great variation among natural leaf surfaces, from species to species and even from leaf to leaf on the same plant, such surfaces introduce an undesirable variable in laboratory spraying experiments. The use of some synthetic surface which can be reproduced accurately and consistently would appear to offer great advantages, in spite of the fact that such a surface probably does not correspond exactly to any known natural surface.

In the tests planned for this apparatus it was necessary to have relatively large areas of sprayed surfaces for subsequent analyses, thus ruling out microscope slides. Preliminary tests were made on glass plates, and on several types of synthetic organic surfaces. Glass plates, when chemically clean, were very easily wetted, and hence did not correspond to most natural surfaces. Cellulose acetate and cellulose nitrate (celluloid or Pyralin) sheets were also extensively tested, and the latter was found to be the most suitable material. The droplet pattern on sheets of this substance were comparable to those observed on many natural surfaces; it was available in quantity at a reasonable cost, and lots secured at different times were found to have very uniform properties. The commercial designation of the material used for all subsequent tests

was *colorless Pyralin, 0.0125 inch thick*. It is available in sheets 20 by 50 inches from the E. I. du Pont de Nemours and Company, and is cut into plates 5 by 5 inches just before use. Rubber gloves are always used in handling and cutting the sheets to avoid contamination. When ready for analysis, the sprayed plates are trimmed to exactly 10 by 10 centimeters, and all analyses are expressed on the basis of 100 square centimeters of surface.

Types of sprayers used.—Two general types of sprayers have been used for laboratory studies on deposit. The first more widely used type is based on the well-known atomizer principle. Most workers using such a sprayer for laboratory studies have disregarded certain rather obvious sources of error involved. Commonly the receptacle containing the liquid to be atomized is below the orifice through which it is discharged. In the case of a homogeneous liquid, of course, the liquid discharged has the same composition as that in the container below. With a solid suspended in the liquid however, the situation is not so simple. Rarely, if ever, are the specific gravities of the suspended phase and the suspending phase the same. In the case of most solids usually used for spraying, the specific gravity is greater than that of the suspending liquid (commonly water), and hence the particles have a tendency to settle to the bottom of the container. They may be kept in a more or less uniform state of suspension by the use of some sort of mechanical stirrer. This is usually done. However, as soon as the suspension is drawn into the delivery tube it is removed from the sphere of action of the stirrer, and the heavy particles begin to settle at once due to the force of gravity. Acting against this force is the upward movement of the suspension caused by the pull from above, which tends to draw both phases upward. The solid particles, however, move upward less rapidly than the liquid phase. This may be observed readily in an all-glass apparatus. The result of this phenomenon is a fractionation: relatively more of the liquid phase and less of the solid phase are discharged than are present in the container. This is shown conclusively by the figures in table 1.

The figures in this table were secured as follows: one liter of a suspension of lead arsenate was prepared and, while thoroughly stirred with a mechanical stirrer, a portion was sprayed through an adjustable atomizer type spray gun (a commercial gun made for automobile painting) with an air pressure of 80 pounds per square inch. Approximately 500 milliliters of the suspension was sprayed out and collected in a tall cylinder so designated as to catch all of the spray discharged. Samples of both the collected spray and the residue remaining in the original container were thoroughly stirred, and 100 ml aliquots withdrawn as rapidly as possible with a pipette. These were transferred to weighed dishes, dried, and the

residue weighed. The suction tube was 9 inches long, and extended nearly to the bottom of the 1.5 liter beaker used to hold the spray suspension.

The figures in table 1 indicate that when using the reservoir below the orifice, the composition of the spray discharged may be decidedly different from that of the original suspension, the discharged spray having on the average only 90.9 per cent as much suspended solids as the original suspension. Other tests with various materials have demonstrated that this error is usually present in this type of apparatus.

Table 1.—Concentration of lead arsenate in the collected discharge from the atomizer compared with the concentration in the suspension remaining in the reservoir; reservoir below atomizer.

Grams PbHAsO₄ per Liter of Spray Suspension	Grams PbHAsO₄ in Collected Spray (as calculated from aliquot)	Grams PbHAsO₄ in Spray in Reservoir (as calculated from aliquot)	Relative Proportion of PbHAsO₄ (original suspension = 100)	
			Collected spray	Reservoir
3.6000	3.348	3.605	93.0	100.1
3.6000	3.320	3.565	92.2	99.0
3.6000	3.499	3.587	97.2	99.6
3.6000	3.466	3.619	96.3	100.5
10.8000	9.616	11.025	89.0	102.1
10.8000	9.580	11.221	88.7	103.9
10.8000	9.212	10.827	85.3	100.3
10.8000	9.209	11.134	85.3	103.1
MEAN			90.9	101.1

Some workers have placed the reservoir above the orifice of the atomizer, thus reversing the gravitational effect. This arrangement was tried, samples being taken in the same manner as those previously described. The results are given in table 2. With the reservoir above the atomizer the mean toxicant concentration in the spray was almost exactly the same as when the suspension was made up, the average being 100.7 per cent. The suspension remaining in the reservoir, however, showed only 95.3 per cent of the original concentration. The difference probably represents a small amount of settling in the reservoir.

The discharge of spray appeared to be more uniform from run to run when the reservoir was placed above the orifice of the atomizer gun. This is shown in figure 4, in which the time required to discharge 500 ml of water was measured at different adjustments of the atomizer gun used. This adjustment regulated the ratio of liquid to air in the discharge, and was made by turning a knurled knob on the gun. Time measurements were made using the reservoir above and below the orifice. The variability of the time measurements in curve A (reservoir below) is noticeably greater than in curve B (reservoir above). The rate of discharge was much more rapid, naturally, when the reservoir was above the orifice.

When using a reservoir with a diameter of 15 cm the withdrawing of 1 liter of liquid lowered the liquid level approximately 5 cm. Extensive tests have demonstrated that this change in level produced a negligible change in rate of discharge; for extreme precision, however, the liquid level may be adjusted to correct for the drop in pressure head or a constant level device may be used.

Table 2.—Concentration of two suspended toxicants in the collected discharge from the atomizer compared with the concentration in the suspension remaining in the reservoir; reservoir above atomizer.

GRAMS TOXICANT ADDED PER LITER OF SPRAY SUSPENSION	GRAMS TOXICANT IN COLLECTED SPRAY (as calculated from aliquot)	GRAMS TOXICANT IN SPRAY IN RESERVOIR (as calculated from aliquot)	RELATIVE PROPORTION OF TOXICANT (original suspension = 100)	
			Collected spray	Reservoir
$PbHAsO_4$— 3.6000	3.60	3.42	100.0	95.0
	3.59	3.40	99.7	94.4
	3.68	3.44	102.2	95.6
	3.70	3.37	102.8	93.6
$PbHAsO_4$—10.8000	10.76	10.60	99.6	98.1
	10.74	10.46	99.4	96.9
	11.05	10.41	102.3	96.4
	11.01	10.25	101.9	94.9
Basicop — 3.6000	3.60	3.51	100.0	97.5
	3.52	3.42	97.8	95.0
	3.68	3.31	102.2	91.9
	3.62	3.37	100.6	93.6
Basicop —10.8000	10.91	10.53	101.0	97.5
	10.98	10.26	101.7	95.0
	10.74	10.28	99.4	95.2
	10.88	10.14	100.7	93.9
MEAN			100.7	95.3

With the adjustable atomizer, which is commonly employed in all studies with this apparatus, it is possible to standardize the delivery volume within narrow limits. It has become standard practice to check the delivery volume for a given period of time before each spraying, as well as to use the same volume of spray suspension in the reservoir in order to eliminate possible variations in the method.

Having determined that the atomizer type sprayer with the reservoir above the orifice discharged a spray having the same composition as the original mixture, a comparison between this type of sprayer and a positive pressure sprayer was made. The positive pressure sprayer is used almost exclusively in commercial operations, and all field sprayers are based on this principle. A miniature pressure sprayer was secured, and fitted with a 10-gallon tank. The tank was equipped with a mechanical agitator which gave thorough agitation at all times. The pump, a single cylinder model, developed a maximum of 300 pounds per square inch pressure, but in these tests was used at 100 pounds per square
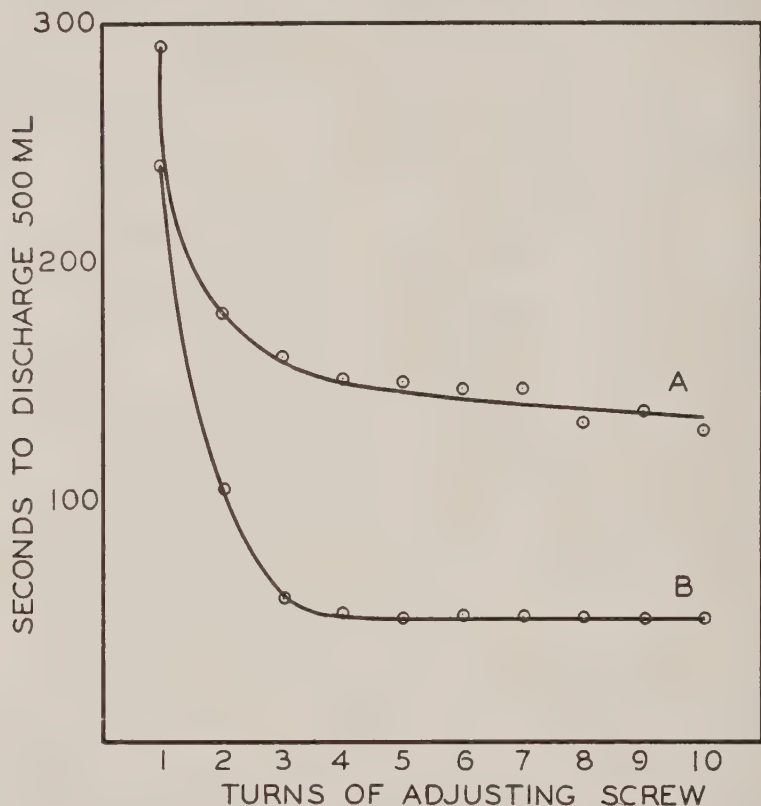
Fig. 4.—Relation between discharge time and atomizer adjustment. Line A represents the results with reservoir below atomizer; line B, with reservoir above atomizer. Note lack of consistency in line A.

inch. The nozzle was a right angle, misting type with an orifice 0.037 inch in diameter, delivering 0.094 gallons per minute at 100 pounds per square inch pressure[2].

Using this outfit, a series of Pyralin plates were sprayed with a suspension of 4 pounds of BORDOW per 100 gallons. Five plates were sprayed one revolution of the wheel, 5 for two revolutions, 5 for three revolutions, and 5 for four revolutions on six different days. The plates were analyzed for copper, and the standard deviations calculated. For comparison, the same procedure was repeated using the atomizer type spray gun mentioned previously, using 80 pounds per square inch air pressure. The results are given in table 3. Each figure represents the average of five plates, although the

standard deviation and group averages were calculated from the individual data.

From table 3 it is apparent that the atomizer sprayer gave much more uniform and reproducible data. The standard deviation of the atomizer sprayed plates varied from 4.6 to 10.9 per cent of the mean values; for the positive pressure apparatus the standard deviations ranged from 10.8 to 18.4 per cent of the mean values.

In order to compare the reproducibility of this method of spraying with the settling tower method of McCallan and Wilcoxon (7), coefficients of variation were calculated in the same manner as reported by these authors. The coefficient of variation between replicate tests (different times) on the rotating table was 69.3 for the positive pressure apparatus and 16.3 for the atomizer. This latter figure is approximately equal to the similar value obtained by McCallan and Wilcoxon for their settling tower technique. The coefficient of variation between plates sprayed at the same time was 5.8 for the positive pressure, and 5.4 for the atomizer sprayer, figures which are again approximately the same as those obtained by the settling tower method. This method of statistical analysis further indicates the superiority of the atomizer as a spraying apparatus over the positive pressure type.

On the basis of these results, the atomizer type sprayer with the reservoir above the orifice was adopted as giving the most consistent and reproducible results.

Table 3.—Uniformity tests conducted with 4 pounds Bordow per 100 gallons of spray suspension; average amounts of copper deposited on 5 plates.

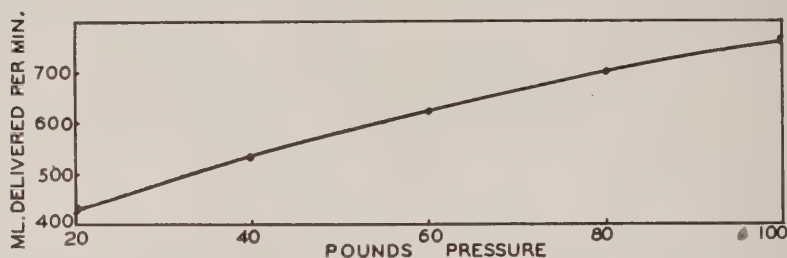|	1 REVOLUTION (micrograms per plate)	2 REVOLUTIONS (micrograms per plate)	3 REVOLUTIONS (micrograms per plate)	4 REVOLUTIONS (micrograms per plate)
		Positive Pressure Pump		
	120	176	236	293
	108	163	225	289
	83	133	187	267
	73	133	161	227
	83	150	200	255
	93	151	193	208
True mean	93	151	203	256
		Atomizer		
	98	164	234	287
	96	192	225	287
	98	175	245	311
	125	163	245	314
	106	168	236	294
	104	156	218	288
True mean	104	170	234	297
Standard Deviation:				
Positive Pressure	17.2	16.3	26.0	34.4
Atomizer	11.3	12.2	13.4	13.8

Fig. 5.—Relation between discharge rate and air pressure using atomizer sprayer with reservoir above outlet.

Effect of air pressure.—In order to ascertain the relation between air pressure and delivery of spray, the atomizer gun was calibrated at different pressures by quantitatively collecting the discharge and measuring its volume. This calibration is shown in figure 5. Water was used as the liquid in this test. It may be seen that the volume of liquid was directly related to the air pressure, although the line is slightly curved, indicating a lower efficiency as the pressure increased.

A series of Pyralin plates sprayed at different pressures indicated that increased delivery does not necessarily result in increased deposit. This is shown in figure 6. In this test the plates were sprayed with a suspension of 3 pounds of Bordow per 100
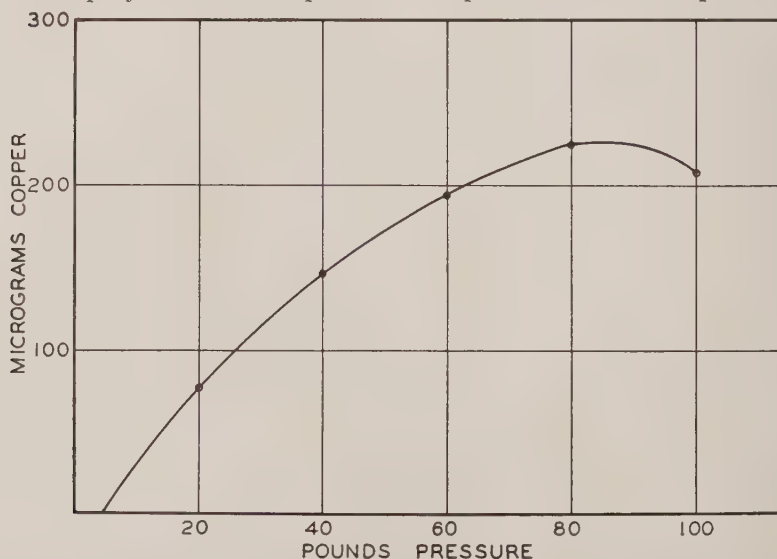

Fig. 6.—Relation between air pressure and amount of spray deposit on *Pyralin* plates.

gallons for 3 revolutions of the rotating table. It may be seen from this figure that the amount of toxicant deposited on the plates increased rather regularly up to and including 80 pounds per square inch air pressure, and then decreased at 100 pounds pressure. Apparently this phenomenon was caused by a deformation of the spray cone at the higher pressure. Eighty pounds per square inch was selected as standard for all subsequent experiments, since it appeared to give maximum deposit on Pyralin plates.

Effect of concentration.—The effect of concentration of toxicant in the spray suspension on the amount deposited upon Pyralin plates is shown in figure 7. Bordow was used as the suspended material in these tests. There appears to be a regular increase in deposit with increases in concentration, but, as in the case of the pressure changes, the response is not linear; that is, 2 pounds of toxicant per 100 gallons gave a deposit of approximately 130 micrograms of copper per plate, while 4 pounds gave only 240 micrograms. The curve, however, is very regular. Since the concentration of toxicant may be varied to suit the type of experiment, this factor has not been standardized, but it has been the custom
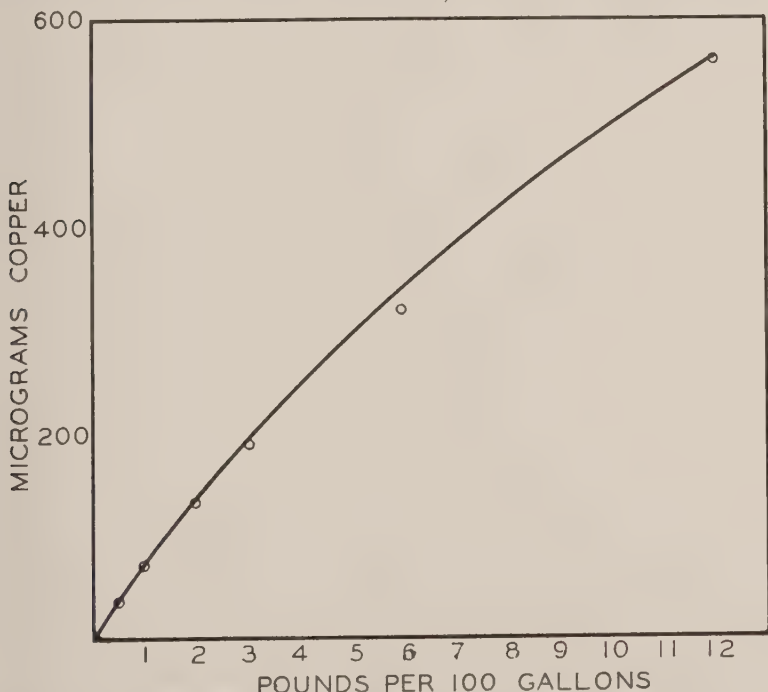

Fig. 7.—Relation between concentration of suspended solids in spray mixture and amount of spray deposited on *Pyralin* plates.

to use most materials at concentrations normally used in the field—usually 2, 3, or 4 pounds per 100 gallons. Lots for laboratory spraying are usually made in 1- or 2-liter quantities.

Effect of time of spraying.—There has been considerable discussion among workers in the field as to the optimum length of time for spraying. To a certain extent this depends upon the problem investigated. For example, if one sprays to the point of drop coalescence, regardless of the length of time required, there is a tendency to mask the effect of added wetting and spreading agents. The determination of this point, too, is rather arbitrary, and depends upon the judgment of the operator. Others make a practice of spraying to the point of run-off following the procedure normally used in field tests. Here again the judgment of the operator may cause differences in the final result. In figure 8 it is possible to see what happens when Pyralin plates are sprayed for different lengths of time. In most of the work done using the complete apparatus, one revolution of the table has been used as a measure of time, rather than seconds or minutes. Using the synchronous motor, the speed of the turntable is constant, and in actual practice one revolution requires approximately four seconds.

In figure 8, line A represents the course of deposit on Pyralin plates sprayed with a suspension containing 3 pounds of Bordow per 100 gallons. This material has the property of forming discrete droplets upon the sprayed surface without wetting it, rather than a continuous film. When sprayed on a surface, therefore, the
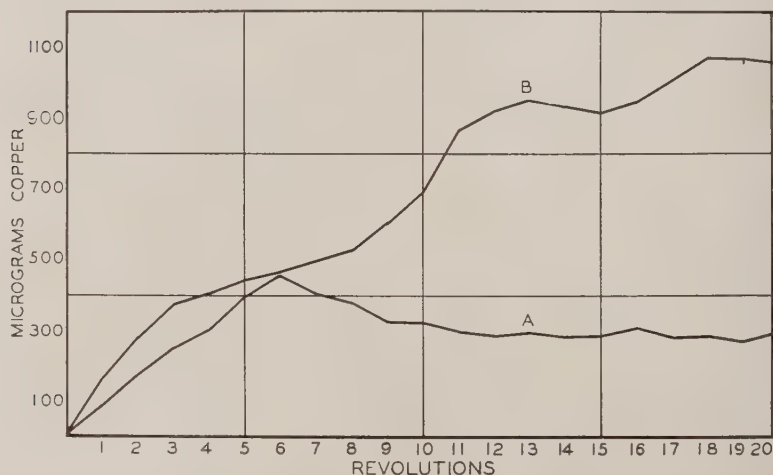
Fig. 8.—Effect of time of spraying on spray deposit on *Pyralin* plates. Line A represents the deposit of Bordow, discontinuous type deposit; line B, bordeaux, continuous or film-type deposit.

droplets grow larger and larger as the spraying time is increased, up to the point where they become so large that they run off due to gravitational pull. In figure 8 this process is readily seen, the deposit increasing in a regular manner up to 6 revolutions. On the seventh revolution some run-off occurred, the deposit decreasing slightly for this reason. During the eighth and ninth revolutions this process continued, until practically all of the large droplets had left the plate through run-off, leaving large areas of the plate free from spray. These areas, consisting mainly of dry plate surface, accepted additional small droplets of spray, and the process reached an equilibrium, run-off being equal to deposit.

The process of deposit is also shown in figure 9, in which a series of photomicrographs of the deposits presented in figure 8, line A, are shown. The progress of the build-up is clearly visible, as well as the "channeling" and secondary deposit on the cleared areas in the plates receiving 10 and 12 revolutions.

In line B, figure 8, the course of deposit for a material which forms a continuous film-type coverage is shown. In this case a 3-6-100 bordeaux mixture was used. Here there was a rather irregular build-up of deposit which continued as long as the spray was applied.

These two materials are by no means representative of all of the insecticide and fungicide sprays used; rather these results are presented to illustrate possible future studies which may prove of interest. The results certainly indicate that spraying beyond the point of run-off may produce quite variable amounts of deposit.

Retention studies.—The apparatus described in this paper was originally designed to be used for retention studies on insecticide and fungicide deposits, and has been used mainly for this type of investigations (9 and 14). A description of the method of operation and the presentation of typical results may be of interest.

Pyralin plates, sprayed with the desired concentration of insecticide or fungicide as described in the earlier portion of this paper, are allowed to dry and are then sprayed with measured amounts of water delivered through the atomizer nozzle. The table upon which the plates are fastened is, or course, rotated during this process, as in the spraying procedure. The plates are allowed to dry, some are removed for analysis, and the remainder subjected to washing. Usually three applications of water have been made, 500, 1500, and 3500 ml of distilled water being used to wash the plates. It is possible by the use of a suitable collection box to measure the amount of water striking each plate. In general, the deposits of most of the less adhesive materials are reduced to roughly one-third after washing with 3500 ml of distilled water.
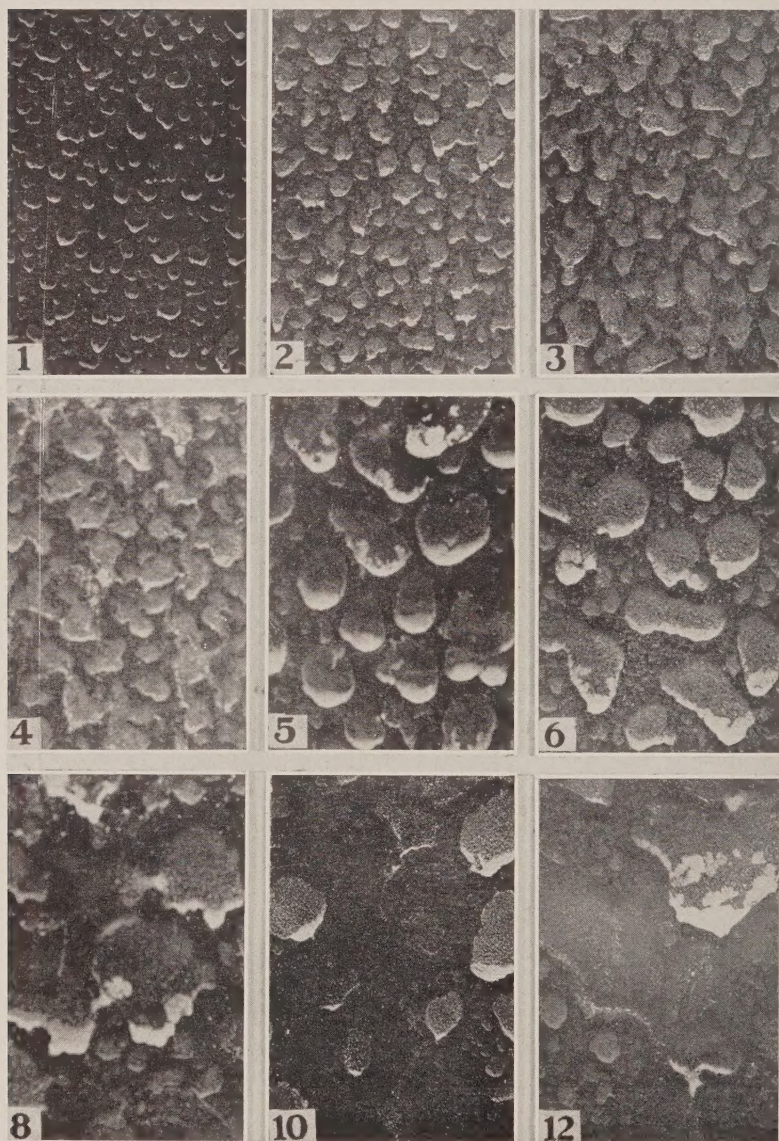
Fig. 9.—Photomicrographs of spray deposits, Bordow, shown in line A, Fig. 8. The numeral in the corner of each photograph indicates the number of revolutions during which the spray was applied. Note increase in droplet size and ultimate run-off.
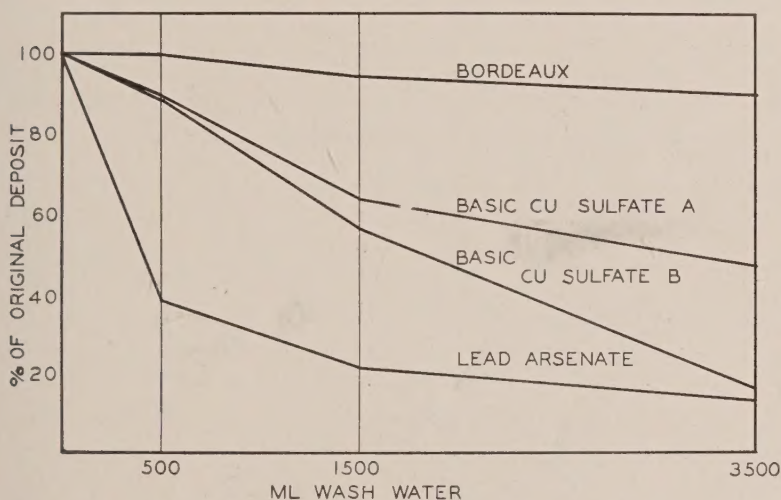
Fig. 10.—Relation between retention of various types of spray deposit and amount of washing.

· Typical results for four materials are given in figure 10. It will be noted that in comparison with the other materials tested, bordeaux mixture exhibited a high degree of retention. The two commercial basic copper sulfates were retained to a less extent, and lead arsenate least of all.
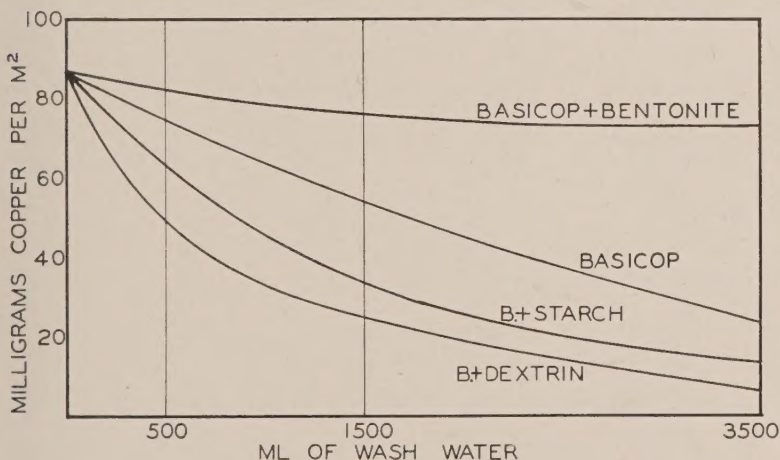

Fig. 11.—Typical results from a study of retention using a commercial copper fungicide with and without adhesive agents.

This method of testing is also well adapted to the study of spray adjuvants, particularly adhesive agents. Figure 11 shows the results of a typical retention study, in which a commercial copper fungicide, BASICOP, was combined with three different adhesives. The differences between the fungicide alone and when used in combination with bentonite, starch, and dextrin are obvious. Comparative studies of a similar nature on several insecticides and fungicides are under way, using a large number of adhesives. Results of this work will be published in the near future.

BIBLIOGRAPHY

(1) Borden, A. D. and G. S. Hensill. 1934. A method of studying comparative oil deposits of proprietary oil emulsions. *Jour. Econ. Ent.* **27**: 834-841.

(2) Dawsey, L. H., A. W. Cressman, and J. Hiley. 1937. The relative quantities of oil deposited upon paraffin-coated plates and upon plant foliage by oil sprays. *Jour. Agr. Res.* **54**: 387-398.

(3) Frear, D. E. H. and H. N. Worthley. 1937. Deposition and retention of sprays on apples. *Pa. Agr. Expt. Sta. Bul.* **344**.

(4) Frear, D. E. H. and H. N. Worthley. 1940. Deposition and retention of sprays on apples. II. *Pa. Agr. Expt. Sta. Bul.* **400**.

(5) Horsfall, J. G., J. W. Heuberger, E. G. Sharvelle, and J. M. Hamilton. 1940. A design for laboratory assay of fungicides. *Phytopath.* **30**: 545-563.

(6) Martin, H. 1932. The laboratory examination of fungicidal dusts and sprays. *Ann. Appl. Biol.* **19**: 263-271.

(7) McCallan, S. E. A. and F. Wilcoxon. 1940. An analysis of factors causing variations in spore germination tests of fungicides. II. Methods of Spraying. *Contrib. Boyce Thompson Inst.* **11**: 309-324.

(8) McCallan, S. E. A., Chairman, 1943. Definitions of fungicide terms. *Phytopath.* **33**: 624-626.

(9) Miller, H. J. 1943. A comparison of laboratory and field methods for evaluating retention and protective value of certain copper fungicides. *Phytopath.* **33**: 899-909.

(10) Moore, W. 1921. Spreading and adherence of arsenical sprays. *Minn. Agr. Expt. Sta. Tech. Bul.* **2**.

(11) Newcomer, E. J. 1926. Laboratory experiments with arsenicals in the control of the codling moth. *Jour. Agr. Res.* **33**: 317-330.

(12) Swingle, M. C., A. M. Phillips, and J. B. Gahan. 1941. Laboratory testing of natural and synthetic organic substances as insecticides. *Jour. Econ. Ent.* **34**: 95-99.

(13) Upholt, W. M. and W. M. Hoskins. 1940. Factors concerned in the deposit of sprays. *Jour. Econ. Ent.* **33**: 102-107.

(14) Worthley, H. N. and D. E. H. Frear. 1942. Deposition of lead from lead arsenate spray mixtures and its retention on pyralin plates and apple leaves and fruits. *Jour. Econ. Ent.* **35**: 205-210.